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# BURNER FOR FABRICATING AEROSOL DOPED WAVEGUIDES

## FIELD OF THE INVENTION

This invention relates to a burner for fabricating aerosol doped waveguides. In particular, the invention relates to a modified burner which enables the in-situ delivery of dopant ions in a single step process to an optical waveguide during the deposition stage of fabrication.

## BACKGROUND OF THE INVENTION

The fabrication of silica based planar waveguides with high ion content by chemical vapour deposition (CVD), and in particular flame hydrolysis deposition (FHD) methods, is already known in the art.

In such fabrication methods it is often desired to introduce dopant ions during the deposition process. The introduction of dopant ions is effected by a number of known methods which suffer to a greater or lesser degree from certain disadvantages. For example, solution doping requires the core which makes up the waveguide to be partially fused and this introduces

several complications.

An alternative method is to use aerosol doping. In aerosol doping droplets of an aqueous solution of the dopant ions are transferred to a modified FHD burner. The water is evaporated to leave submicron dopant ion particles. The dopant ions are then oxidised in the burner flame and can be distributed during the deposition stage of fabricating the waveguide.

It is known to modify conventional FHD burners to incorporate an extra port for the aerosol feed. A problem arises, however, when such burners are used in the fabrication of heavily doped waveguides. High dopant ion levels require high concentrations of the aqueous dopant ion solution. During the evaporation of the solvent in highly concentrated solutions, more dopant ions condense around the aerosol inlet port than would do with a less concentrated solution. This build up of condensed ions can create blockages. The present invention seeks to provide a modified burner design which obviates or mitigates the problems heretofore mentioned.

## SUMMARY OF THE INVENTION

In accordance with the present invention there is provided a burner for fabricating aerosol doped waveguides, the burner including:

a plurality of inlet ports each connected to a respective torch conduit, said torch conduit connecting its respective inlet port to a gas mixing region; and including a gas expansion chamber provided for at least one of said inlet ports upstream of said gas mixing region.

Preferably, the gas expansion chamber is in the form of a reservoir chamber.

Preferably, the gas expansion chamber is located at the junction of an inlet port and the respective torch conduit.

Alternatively, the gas expansion chamber is located upstream of the junction between the inlet port and the respective torch conduit.

Alternatively, the gas expansion chamber is located downstream of the junction of an inlet port and the respective torch conduit.

Preferably, said inlet ports feed oxygen, hydrogen, waveguide deposition material carried by a carrier gas, and aerosol droplets of a dopant ion solution carried by a carrier gas to the said burner.

Preferably, the hydrogen port is located downstream of the waveguide deposition material inlet port.

Preferably, the aerosol inlet port is located downstream of the hydrogen inlet port.

Preferably, the oxygen inlet port is located downstream of the aerosol inlet port.

Preferably, said at least one inlet port is located in a radial plane with respect to a longitudinal axis of the burner which differs from a radial plane containing said other inlet ports.

Preferably, said at least one inlet port is located in a plane orientated at 180° to the radial plane of the

other inlet ports.

Preferably, said at least one inlet port is orientated at a first angle with respect to the burner axis, and wherein the other inlet ports are orientated at a second angle with respect to the burner axis, said first angle being less than said second angle.

Preferably, said first angle lies in the range 5° to 45°.

Preferably, said first angle lies in the range 5° to 25°.

Preferably, said at least one inlet port is an aerosol inlet port for providing aerosol droplets of a dopant ion solution to said burner.

## DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention will now be described by way of example only, with reference to the drawings in which:

Fig. 1 is an FHD burner already known in the prior art;

Fig. 2 is a cross-section through an FHD burner of the type shown in Fig. 1; and

Fig. 3 is a cross-section through a modified FHD burner according to the present invention.

## DETAILED DESCRIPTION OF THE INVENTION

Referring to the drawings, Fig. 1 illustrates a FHD burner 1 already known in the art. The burner 1 has

four feed inlet ports: a halide inlet port 2, a hydrogen inlet port 3, an aerosol inlet port 4, and an oxygen inlet port 5. The halide inlet port 2 feeds the burner 1 with halide deposition materials, for example, $SiCl_3$, $PCl_3$, etc carried by a suitable carrier gas, for example, $N_2$. The inlet ports 2,3 4 and 5 communicate with a gas mixing region 8 at the output of the burner 1.

The aerosol inlet port 4 supplies aerosol droplets of a dopant ion solution, for example, 0.2 M aqueous $ErCl_3$. An atomizer 6 is used to generate the aerosol droplets of the dopant ion solution. The aerosol droplets are carried by a carrier gas, for example, $N_2$ to the aerosol inlet port 4 of the burner 1. The water solvent is then evaporated to leave submicron particles of the dopant ions (here $Er^{+3}$) which are prone to condense at the inlet port 4. For solution strengths above 0.2M, the build up of condensed dopant ions can create a blockage 7 which can clog the inlet port 4. This blockage 7 occurs before the dopant ions react in the gas mixing reaction zone 8, which affects the rate at which the dopant ions are incorporated during fabrication of a waveguide 9. The blockage 7 arises due to the combination of an abrupt reduction in pipe volume and the change in directionality of the carrier gas flow ($\theta = 68°$ from the torch axis (X in Fig. 1)).

Referring now to Fig. 2, there is shown a cross-section through this type of conventional burner 1. The inlet ports 2, 3, 4 and 5 are all aligned at the same angle $\theta$ to the torch axis X, and transfer the feed gases (the gas carrying the halide deposition materials, hydrogen, the gas carrying the dopant ions, and oxygen) into concentric torch conduits 10, 11, 12 and 13 respectively. The halide torch conduit 10, hydrogen

torch conduit 11, aerosol torch conduit 12, and oxygen torch conduit 13 deliver the feed gases to the gas mixing reaction zone 8 located in the burner nozzle 14 where the dopant ions are oxidised in the burner flame. The oxidised dopant ions are then incorporated during the deposition of the layers (not shown) which form the waveguide 9 (shown in Fig.1) a single step process.

Referring now to Fig. 3, there is shown a modified burner 15 made in accordance with the invention for introducing rare earth dopant ions, for example, $Er^{+3}$, during fabrication of a waveguide (not shown).

The burner 15 has four feed inlet ports: a halide inlet port 16, a hydrogen inlet port 17, an aerosol inlet port 18, and an oxygen inlet port 19. The halide inlet port 16 supplies the deposition materials, for example, $SiCl_3$, $PCl_3$, etc, which are carried by a suitable carrier gas, for example, $N_2$. The aerosol inlet port 18 supplies aerosol droplets of a dopant ion solution, for example, aqueous $ErCl_3$.

The halide inlet port 16, hydrogen port 17, and oxygen port 19 are located in the same radial plane radiating from the torch axis Y and can be all aligned at the same angle $\theta 1$ to the torch axis Y. The aerosol inlet port 18 is located in a different radial plane (for example, it may be displaced by 180° from the plane in which the inlet ports 16, 17 and 19 are located) and is positioned at a different angle $\theta 2$ with respect to the torch axis Y. The inlet ports 16, 17, 18 and 19 transfer the feed gases into respective concentric torch conduits 20, 21, 22 and 23. The halide torch conduit 20, hydrogen torch conduit 21, aerosol torch conduit 22, and oxygen torch conduit 23 deliver their respective feed gases to a gas mixing reaction zone 24

where the dopant ions, in this example $Er^{+3}$, are oxidised in the burner flame (not shown).

The aerosol inlet port 18 has a modified structure, compared to the aerosol inlet port 4 of prior art burner 1. The aerosol conduit 22 is expanded at the region where it connects with aerosol inlet port 18 to form a gas expansion chamber 25 (here in the form of a reservoir chamber). The gas expansion chamber 25 provides an increase in the volume of the aerosol inlet port 18 and helps to maintain the concentration of dopant ions and to mitigate the build up of condensed dopant ions during evaporation of the aqueous dopant ion solution.

The gas expansion chamber 25 enables the evaporation of the dopant ion solvent to occur without the dopant ions condensing at the base of the aerosol inlet port 18 forming a blockage at the base of the aerosol inlet port 18.

A suitable volume for the gas expansion chamber lies in the range of 2500 $mm^3$ to 5000 $mm^3$ for an aerosol feed carrier gas flow rate of 3 litres/min, an aerosol inlet port 18 internal diameter of 5.5 mm, and an aerosol conduit 22 internal diameter of 14 mm.

In the preferred embodiment, the gas expansion chamber 25 is circular in radial cross-section and elliptical in axial cross-section and is provided at the junction of the aerosol inlet port 18 with the aerosol torch conduit 22 by expanding the internal diameter of the aerosol conduit 22. Alternatively, the gas expansion chamber may have a different shape and/or configuration. It can also be located at other points where evaporation of the dopant ion solution occurs,

for example upstream along the aerosol inlet port 18 or downstream along the aerosol conduit 22.

The prevention of a blockage occurring as the dopant ions enter the aerosol conduit 22 is further assisted by reducing the angle of directionality θ2 (the angle the aerosol inlet port makes with the torch axis (Y in Fig. 3)). In the preferred embodiment, significant reduction in the amount of condensation is provided by θ2 being substantially equal to 10°, which is in a preferred range of 5° to 25°. A reduction in the amount of condensation is also achieved if θ2 is in the range of 25° to 45°.

The dimensions of the aerosol conduit 22 are selected to optimise the dopant process and to provide directionality to the flame whilst reducing the burner nozzle 26 temperature to below 1300°C. This prevents devitrification of the nozzle 26 which would otherwise provide unwanted contaminants.

In the preferred embodiment, with a deposition rate of 1 μm of base material per traversal of the FHD burner, it is possible to achieve doping levels of up to 0.72 wt% for an $ErCl_3$ solution strength of 1M with a carrier gas flow rate of 2.4 litre $min^{-1}$. Higher dopant levels can be achieved, for example, by maintaining the rare earth dopant conditions and reducing the halide flow rates or by increasing the concentration of the rare earth dopant solution.

Other dopant ions, for example, rare earth or heavy metal ions and combinations of ions can incorporated using the burner 15 into the deposition stage. Suitable solutions including rare earth and/or heavy metal ions can be prepared at much higher

concentrations than were hitherto known in the art without any accretion clogging the burner 15.

For example, a Nd doped planar silica ($SiO_2$ - $P_2O_5$) waveguide can be fabricated using the burner 15. An Nd/Al aqueous solution of 0.5M/0.4M can be used to provide the waveguide with dopant ion concentrations of 0.25 wt% for Nd and 0.04 wt% for Al.

The modified FHD burner 15 therefore enables greater control of the ion doping process during the deposition stage of fabricating the waveguide. One or more ion species can be introduced during the deposition stage of fabricating the waveguide in a controlled manner to produce waveguides with more uniform and much higher dopant ion concentrations than known from the prior art.

While several embodiments of the present invention have been described and illustrated, it will be apparent to those skilled in the art once given this disclosure that various modifications, changes, improvements and variations may be made without departing from the spirit or scope of this invention.